BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Finite-Thrust Transfers to Synchronous Orbit and Translunar Injection

DATE: September 4, 1968

FROM: A. L. Schreiber

ABSTRACT

Engine burn time and losses due to gravity were computed as a function of thrust/weight ratio for two missions: (1) injection onto a translunar trajectory, and (2) transfer from a 100 nautical mile circular orbit to synchronous orbit altitude. The variation of the circularization impulse required at synchronous altitude with thrust/weight ratio was also determined.

Data were obtained for two values of specific impulse, one representative of nuclear rockets and the other of advanced cryogenic chemical rockets.

(NASA-CR-73517) FINITE-THRUST TRANSFERS TO SYNCHRONOUS ORBIT AND TRANSLUNAR INJECTION (Bellcomm, Inc.) 9 p

N79-71867

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Unclas
11292

FF No. 602

(PAGES)

CR-73517

(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

[redacted]

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MEMORANDUM FOR FILE

Introduction

The purpose of this study was to provide data from which thrust/weight effects can be evaluated in performance analysis. Losses due to gravity were examined for transfer to an ellipse with a specified apoapsis altitude from a 100 nautical mile circular earth orbit. The first case was a translunar injection burn, and the second was a burn to reach synchronous-orbit altitude. In both cases, a range of thrust/weight ratios and specific impulses (I_{sp}) of 460 seconds and 825 seconds were considered.

In all cases, the equations of motion were integrated with thrust tangent to the velocity vector (as essentially optimal steering) until the instantaneous osculating ellipse had attained the required apoapsis altitude. The fuel consumption and the equivalent ΔV_{total} ($\equiv I_{sp} g \ln W_o/W_f$) are thereby determined. The differences between the impulsive ΔV_{ideal} required for transfer to an ellipse of the same apoapsis altitude and ΔV_{total} is the loss due to gravity.

Translunar Injection Burn

An impulse of 10,250 feet/second, added to circular velocity in a 100 n. m. earth orbit, was used to characterize a translunar trajectory. The finite burns were then targeted to reach the same apoapsis altitude (182,294 n. m.). Thrust to initial gross weight ratios of .05 - .60 were examined.

The losses for both I_{sp}'s are given in Figure 1, and the burn times in Figure 2.

Burn to Reach Synchronous Orbit Altitude

An impulse of 8,079 feet/second added in a 100 nautical mile circular earth orbit characterizes transfer to synchronous orbit altitude. The finite burns were then targeted to reach the same apoapsis altitude (19,441 n. m.). Thrust to initial gross weight ratios of .035 to .600 were examined.

The losses for both I_{sp}'s are given in Figure 3 and burn times in Figure 4.

For the synchronous-orbit case, the circularizing ΔV was also determined. This was computed as an impulse at apoapsis rather than a finite burn since gravity losses at this altitude are negligible. These circularizing impulses are given both with and without a 28.5° plane change (i.e. changing to an equatorial orbit after a due-east launch from Cape Kennedy) and for both I_{sp}'s in Figure 5. Burnout altitudes (altitude of termination of the finite burn) are given in Figure 6. The lower thrust/weight levels lead to higher burnout altitudes. The ellipses associated with these higher burnout altitudes have higher apoapsis velocities which are responsible for the lower circularizing ΔV requirements.

Effect of I_{sp}

Initial accelerations are identical for the same thrust/weight ratio and different I_{sp}'s. However the I_{sp}'s define different fuel-flow rates which then cause the acceleration histories of the two burns to diverge. This results in longer burn times and higher gravity losses for the higher I_{sp} at a given thrust/weight ratio.

A. L. Schreiber

A. L. Schreiber

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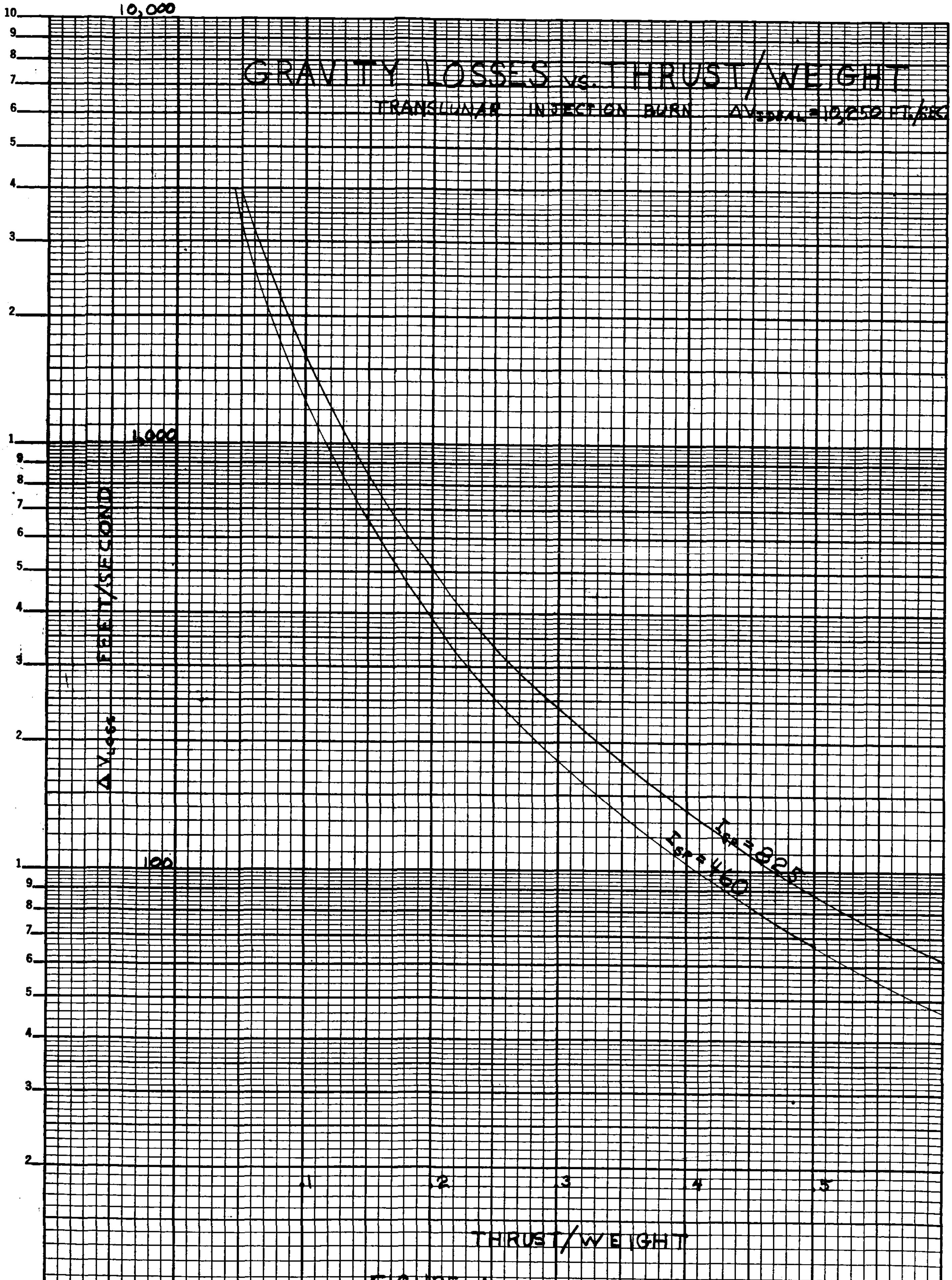
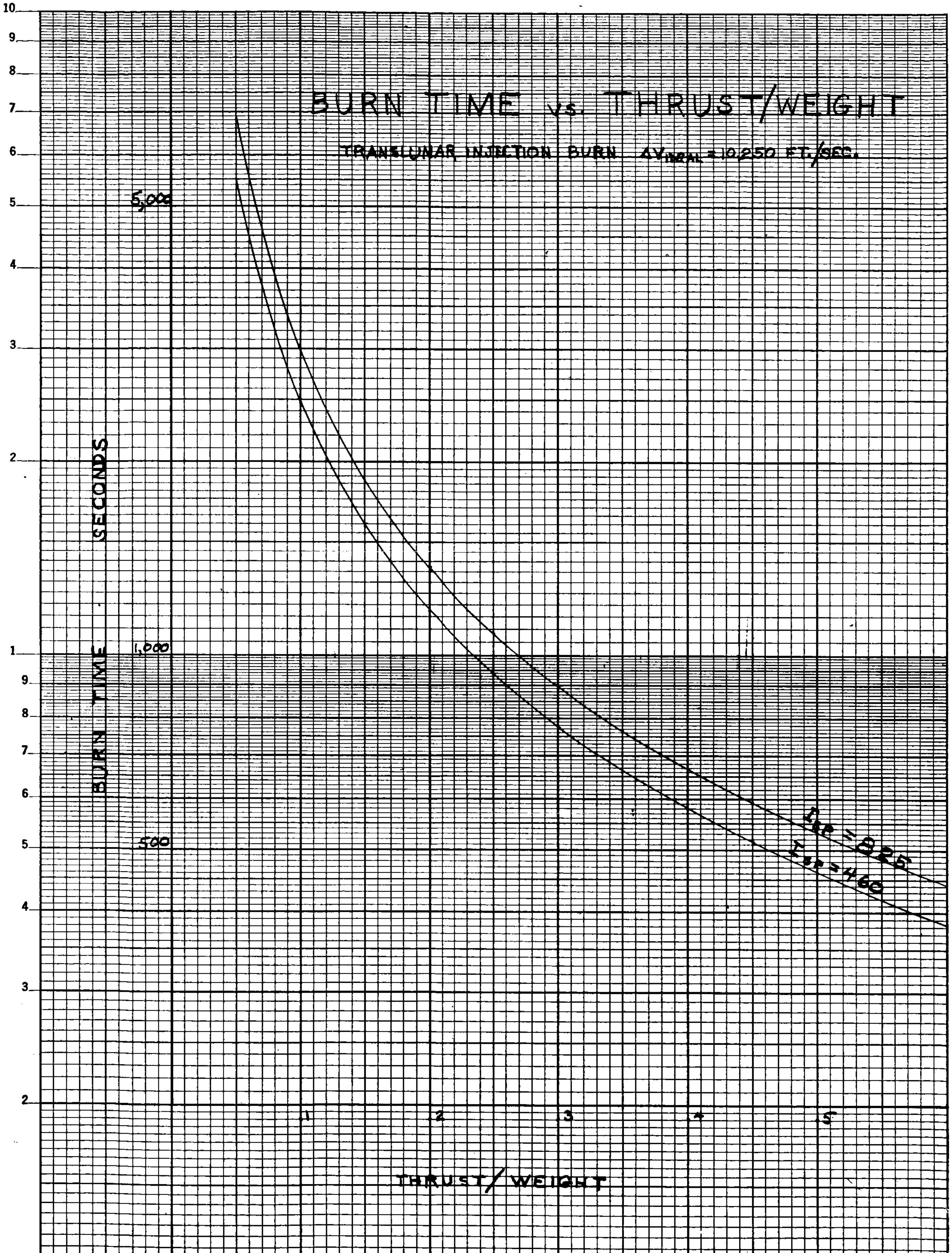

GRAVITY LOSSES vs. THRUST/WEIGHT
TRANSLUNAR INJECTION BURN ΔV_{IDEAL} = 10,250 FT./SEC.
10,000
1,000
100
ΔV_{LOSS} FEET/SECOND
I_{SP} = 825
I_{SP} = 460
.1
.2
.3
.4
.5
THRUST/WEIGHT

FIGURE 1



BURN TIME vs. THRUST/WEIGHT
TRANSLUNAR INJECTION BURN ΔV IDEAL = 10,250 FT./SEC.
BURN TIME SECONDS
5,000
1,000
500
THRUST/WEIGHT
1
2
3
4
5
I SP = 825
I SP = 460

FIGURE 2

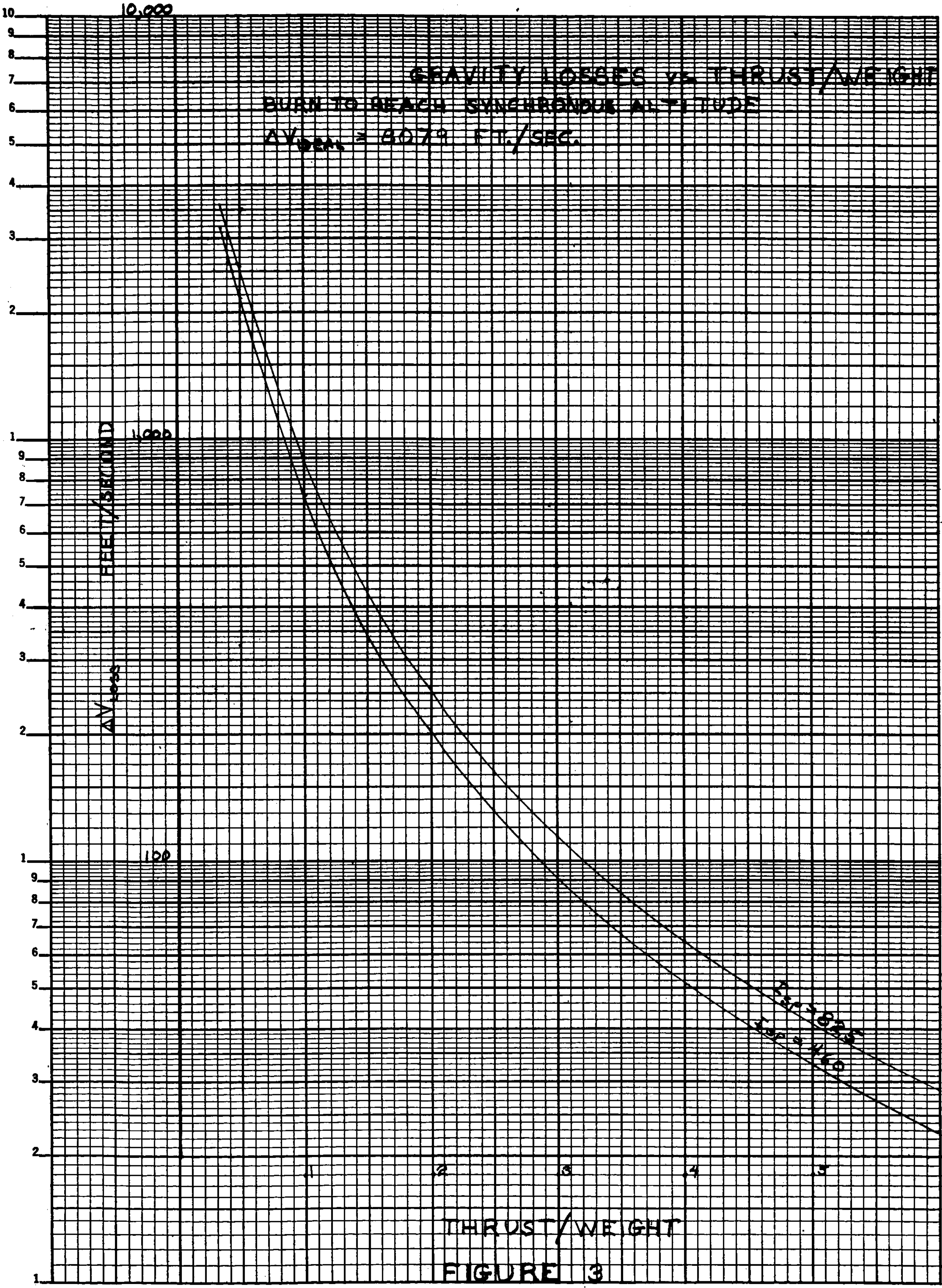

GRAVITY LOSSES vs. THRUST/WEIGHT
BURN TO REACH SYNCHRONOUS ALTITUDE
ΔV IDEAL = 8079 FT./SEC.
ΔV LOSS FEET/SECOND
10,000
1,000
100
THRUST/WEIGHT
ISP = 325
ISP = 460

FIGURE 3

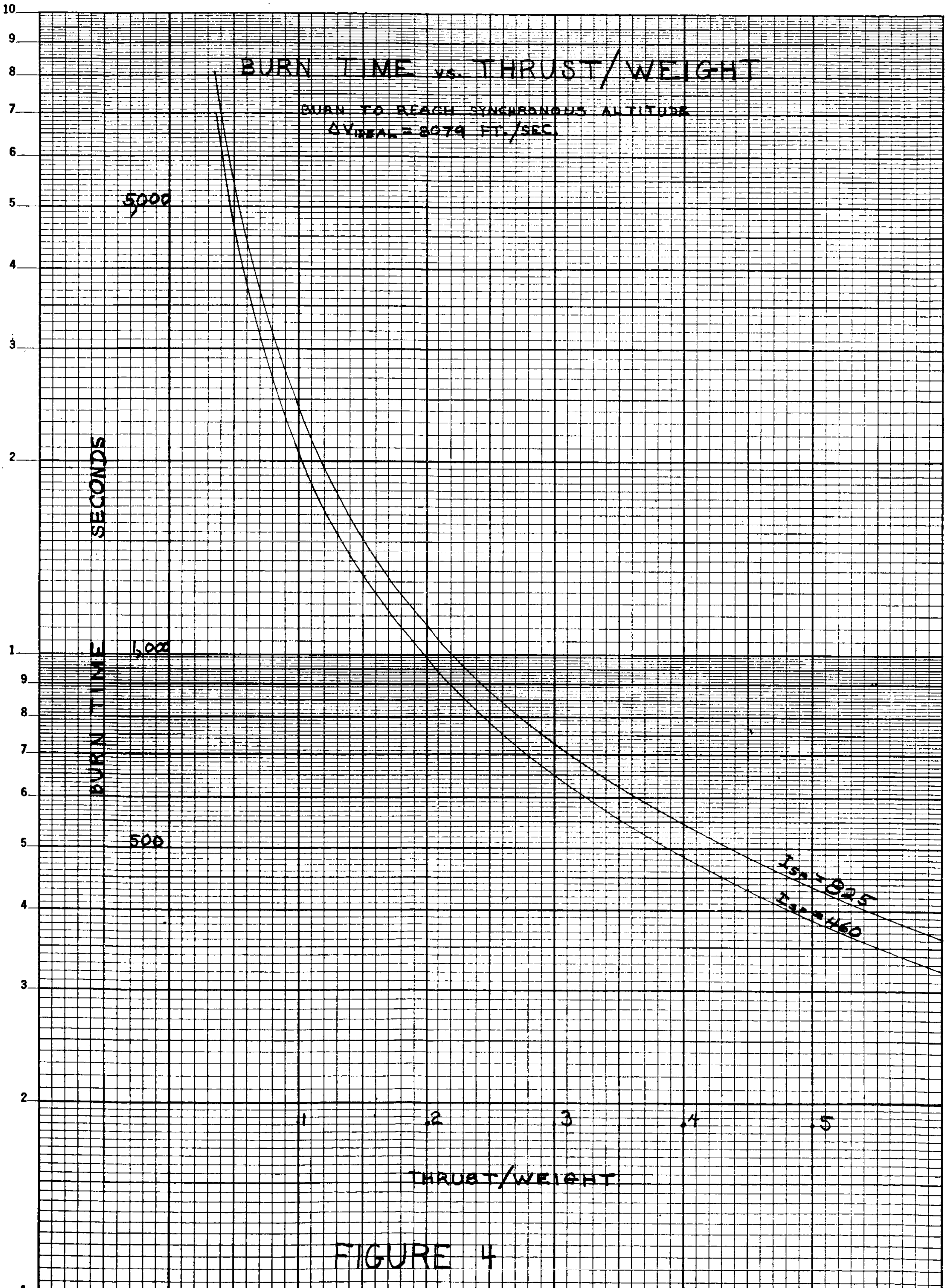
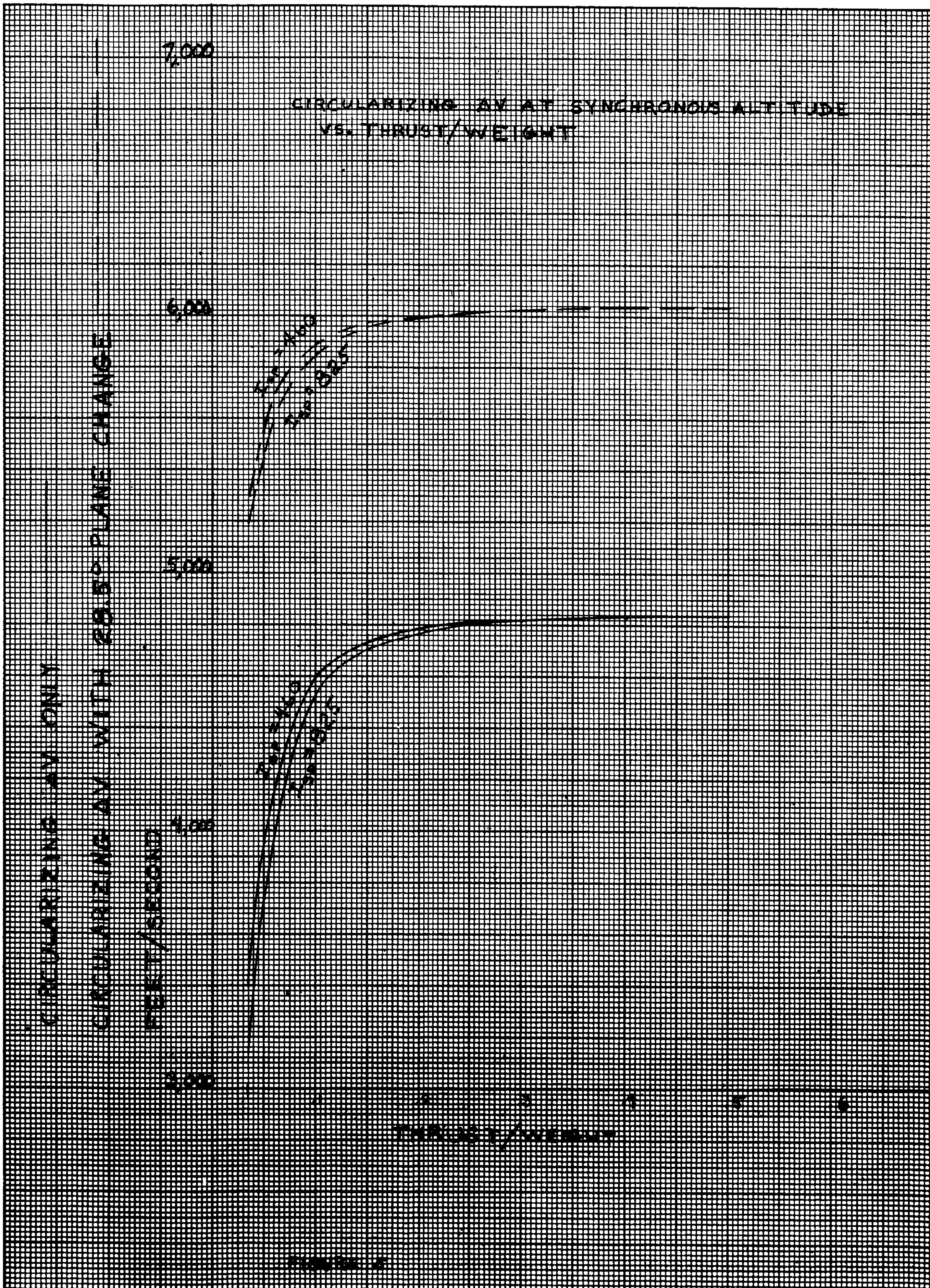
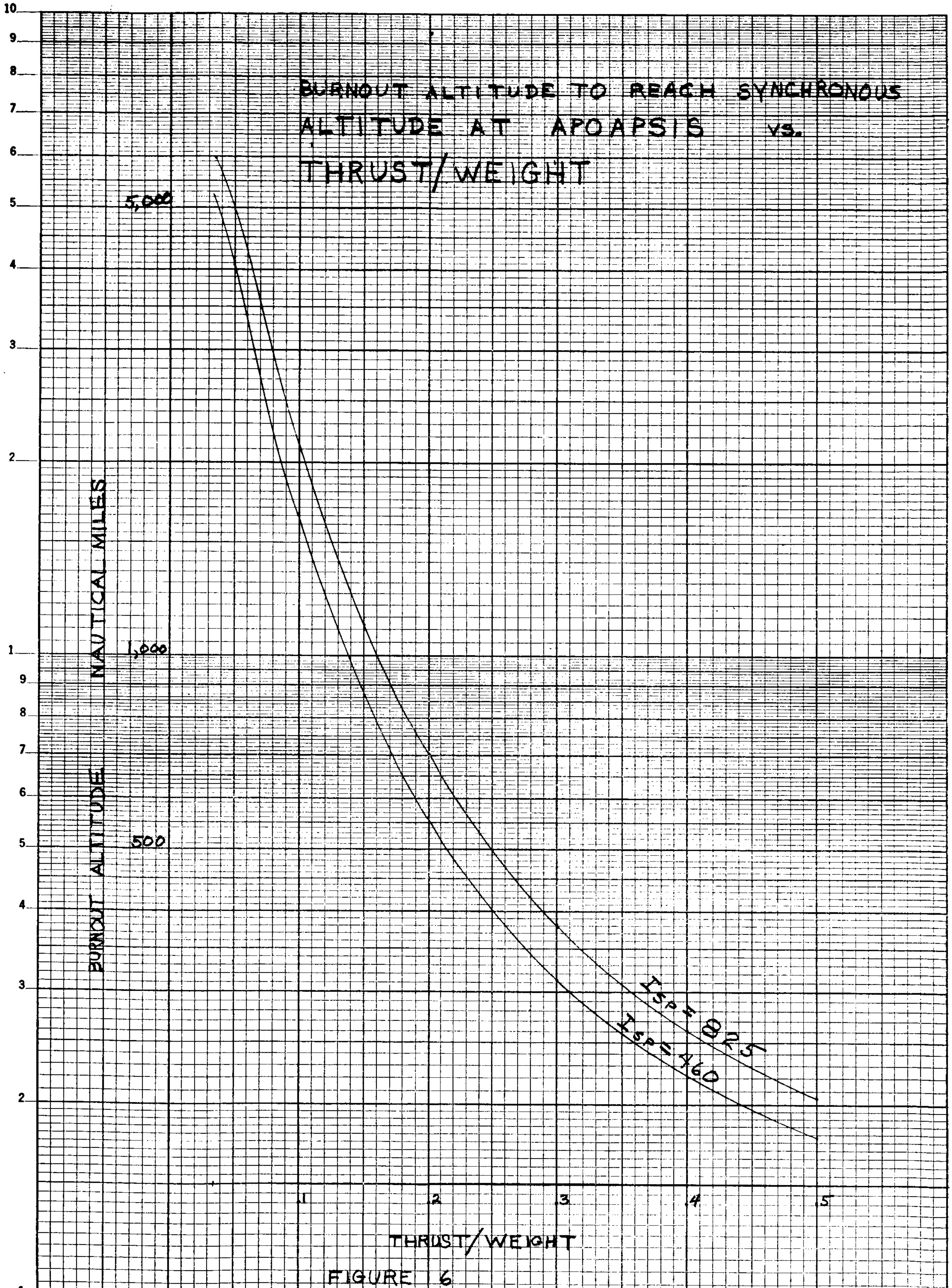

BURN TIME vs. THRUST/WEIGHT
BURN TO REACH SYNCHRONOUS ALTITUDE
ΔV IDEAL = 8079 FT./SEC.
BURN TIME SECONDS
5000
1,000
500
.1
.2
.3
.4
.5
THRUST/WEIGHT
Isp = 325
Isp = 460

FIGURE 4



CIRCULARIZING ΔV AT SYNCHRONOUS ALTITUDE
VS. THRUST/WEIGHT
7,000
6,000
5,000
4,000
3,000
CIRCULARIZING ΔV ONLY
CIRCULARIZING ΔV WITH 28.5° PLANE CHANGE
FEET/SECOND
2
3
4
5
6
THRUST/WEIGHT



BURNOUT ALTITUDE TO REACH SYNCHRONOUS
ALTITUDE AT APOAPSIS VS.
THRUST/WEIGHT
BURNOUT ALTITUDE NAUTICAL MILES
5,000
1,000
500
.1
.2
.3
.4
.5
THRUST/WEIGHT
Isp = 460

FIGURE 6

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